Flood Hydrology and the Floodplain

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The floods of 1993 offer a list of subjects for detailed study. These involve both the separate actions and the interactions of forces and parameters in geomorphology, hydraulics, hydrology, physical geography, economics, engineering and planning. Whether the pressures for recovery and rebuilding will permit the possible and needed study of these inter-relationships remains to be seen. There is the perceived need to "do something" and the well-known decay of attention and interest as flood becomes memory.

There has already been a considerable fortune spent to help individuals, businesses, and communities recover from direct and indirect losses. It is certain that much more will be spent in reconstruction. It is moot whether this investment will take advantage of what might be learned from this bad experience or be directed to continue past practices with only cosmetic changes.

In the matter of floodplain management, most people agree that some combination of structural and non-structural methods are probably a better approach than the previous complete reliance on dams and levees. But so far there has been little study of the details of how floodplain areas can be used under present levels of development to fulfill their geomorphic purpose. The present essay does not deal with the many important aspects of floodproofing, insurance, moving structures to higher ground, rehabilitation of wetlands, and floodplain zoning, all of which should play a role in modern floodplain management. It does relate to one of the two goals of national floodplain management stated by the National Review Committee, "to protect and enhance the natural values of the nation's floodplains" (Natural Hazards Research and Applications Information Center, 1992). One such natural value is the role that overflow areas may play in flood peak reduction by the provision of temporary storage.

In the popular press there is often a comparison drawn between the overflow of the floodplain under natural conditions and the constriction of the channel between levees and floodwalls. Though the theory of flood peak reduction is clear, the amount and importance of such action under present conditions of flood plain use have not been evaluated. A detailed analysis is long overdue for it was shown more than three decades ago that dams for flood control are effective immediately downstream but their effect diminishes rapidly with distance; and as far as a series of small headwater dams is concerned, they are essentially ineffective under conditions in which major floods occur on large river basins (Leopold and Maddock, 1954).

The basic data needed to make such an evaluation are not immediately available nor have the actual computations been made. The basis for such calculation is known at least in theory.

Channel Storage and Flood Stage

A reservoir for flood control is used to make outflow rate downstream much less than the inflow rate. When the incoming flood decreases, the accumulated storage can be allowed to flow out at an acceptable rate. The buildup and decrease of volume stored in the reservoir is used to control the outflow.

A river channel is long, but has both depth and width. A reach of channel can contain a large volume of water within its banks. A reach of river is an elongate reservoir. The volume within its banks provides the same function as a reservoir. This volume and its action are referred as channel storage.

When a river overflows on to its floodplain, the reach of valley has even larger storage volume than merely within the channel itself. Channel storage is only a small factor in a big flood. Floodplain storage is dominant if it is available under natural conditions. Thus the river and its overflow area constitute a reservoir provided by nature. Reservoir action ameliorates the flood peak. How much amelioration occurs and its value have not been determined in river valleys where the effect might potentially be most important. One of the reasons is that dikes were being built before the era of modern hydraulic analyses.

Most floodplains of rivers are built primarily by lateral movement of the channel, erosion of a concave bank and simultaneous extension of the point bar building out from the convex bank. But on large rivers carrying much fine sediment, overbank deposition can be an important contributor to flood- plain construction. Because a river builds and maintains its channel large enough to contain only moderate discharge, the flow over the floodplain is a necessity, for the floodplain is part of the river. Most unregulated rivers in the world, large and small, reach or exceed bank full conditions about once a year.

Levees obviously are for the purpose of keeping the river from overflowing its floodplain. But they have the disadvantage of increasing river stagewater surface level because the width is restricted and temporary storage over the floodplain has been eliminated. This increase in stage can be large.

The Corps of Engineers has published tabulations of the highest stages of the Mississippi River for each year since the mid-19th century to 1960. Many began about 1860 and some as early as 1852. There is a similar Corps report on annual maximum discharges to 1963. Intensive flood control structural work began about 1927. Using data for the years of high flow prior to 1927, discharge rating curves for some stations were plotted, that is plots of concurrent discharge and stage data. In a circular dated September 1993, the U.S. Geological Survey published the maximum discharge and stage for the 1993 flood at many stations (Parrett, et al., 1993). Comparison of these data with the pre-flood-control condition was possible for three stations on the Mississippi River. The tabulation below shows the stage in feet of the peak discharge of 1993 as observed, and what it would have been in the pre-1927 condition.

Table 1
Stages of Peak Discharge for 1993 and Pre-1927
For Three Stations on the Mississippi River

Station	year	stage/ ft.	pre-1927 stage/ ft.	difference, ft.
St. Louis, Mo.	1993	49	39	10
	1973	43	35	8
	1982	39	34	5
Chester, Ill.	1993	49	33	16
	1973	43	32	11
	1982	41	31	10
Keokuk, Iowa	1993	27	23	4

These data do not deal with the effect of any particular levee, series of levees, or reservoirs. The data merely show the cumulative effect of all the changes influencing the channel.

A valuable type of analysis is exemplified by the recent study by Douglas T. Shaw published in the *St. Louis Post-Dispatch* in which he computed the changes in flood stage at various points in a 34 mile reach of the Mississippi River centered around the St. Louis region, had various levees held or had failed during the 1993 flood (*St. Louis Post-Dispatch*, 1993). This type of computational problem has great educational value not only to the public but also to the engineering profession. He showed how levee failure at one or several places has an effect on flood stages both upstream and downstream of the failures. Depending on what held and what failed, the consequences vary from one reach to another.

The Corps of Engineers has made studies of the water surface profiles along the Mississippi under various assumptions of discharge and tributary contribution, a useful summary of which is in Moore (1972). As might be expected, the alternative computations in those studies assume that the levees and dams function as planned. But this summary has the advantage of showing the effects of various intensities of engineering works. The levee grade, 1 or 2 foot freeboard above maximum water stage, is presented for a series of stations, computed for the conditions of 1928 before the majority of levees were completed, and conditions in 1941 and 1956. These comparisons show the rise in the river stage in later as compared with earlier years, just as did my computations tabulated above.

The proposal in the present essay is a broader consideration of the possibility of utilizing the natural function of floodplains in conjunction with engineering works such as levees and dams. The extent of flood damage reduction achieved by allowing some floodplain areas to flood, its potential benefits and costs, the locations and distribution of such benefits and costs, have not been studied in an organized way.

Because of its nearly level surface and its alluvial soil, a floodplain invites modern development for transportation, agriculture, industry and housing. As a result, when the river uses its floodplain, damage to human development is high and very disruptive. But in actuality, housing, industry, transportation, and infrastructure development cover only a minor part of the floodplain area on most rivers. By far the greatest percentage of the area is in agriculture, in which cropland is greater in area than pasture, woodland, or wetland. But actual use is determined by the desires of landowners, by the nature of the soil and the topography, and by the perceived degree of protection from flooding. It is influenced by land values, by available infrastructure, and by historical accident.

An approach not previously incorporated into flood control policy is allocating the non-development uses of the floodplain, especially agriculture, less than 100 percent of the time. Such allocation must depend on purchase of land or purchase of easements, and by such studies that will persuade owners and the public that the results will be advantageous. This puts a premium on sophisticated studies of the dynamic interrelationships among topographic, hydraulic, hydrologic, agricultural, and economic factors.

Aspects of the physical studies needed are mentioned below with some indication of the possibility of their accomplishment.

Computation of Flood Stage Reduction by Temporary Storage

One of the basic tools in hydraulic practice is the computation of the relation among inflow, outflow, and change of storage. Certain measurements are necessary. The stage-volume information for a reservoir is simple enough. For a river channel and floodplain, the needed information is clear enough in theory. The relation of volume of storage as a function of stage at the downstream end requires topographic detail of the area over which water will be allowed to flood. But unlike simple reservoir storage, the computation of storage and flow involves the dynamic relation among width, depth, slope, velocity, and hydraulic roughness. Shaw has shown that such computations are possible but that data needed are severely limited.

These relationships are greatly assisted by field observational data on flow conditions over floodplains. For many rivers of small to moderate size, current-meter data on velocity and depth have been recorded by the hydrographers of the U.S. Geological Survey. Such information should be extracted from the stored original field notes and analyzed. Then an effort should be instituted to observe in more detail when overflow conditions present themselves.

Shaw pointed out that computations are also dependent on the detail available to describe the topographic configuration of area flooded. As far as the detailed mapping of floodplain areas is concerned, the Topographic Division of the U.S. Geological Survey has both the photographs and technical capability of providing the needed maps.

Whereas the flood peak reduction by a single reservoir is easy to compute, the problem in a river system is more complicated. First, in a river valley the local topography changes from reach to reach along the valley. Valley width changes. Terrace remnants may confine the floodplain in some reaches, and cross-valley features such as highways or railroads alter the flow paths of overflow. So the stage-outflow relation is different from one reach to another. Second, tributaries enter and the timing of flood peaks of tributary and master stream is determined by the local distribution of outflow in each individual storm. Thus the reach-to-reach computation of inflow-storage-outflow relation is complex. The development of the needed data and computational procedures, though not presently complete, is within reach.

Assume that selected reaches of valley in the Mississippi-Missouri system were surveyed in topographic detail, and that records of flood heights and discharges for 1993 and previous floods were studied. Computations could be made using past flood data as examples of how much peak reduction of discharge could be accomplished by flooding selected areas of floodplain now in agricultural use. Flood history has shown that most floodplain area would not be flooded except for short periods of time and infrequently.

Under various assumptions of flood characteristics, frequency, and duration, selected areas of floodplain could be designated as efficient for peak reduction. The government would buy easements from the owners to permit infrequent flooding of these designated land areas. Within those areas, valuable structures such as homes, barns, and special zones would be flood proofed by various means including building local levees around them. The idea would be to put money into study, purchase of easements, and local flood proofing rather than in disaster relief.

My own field experience observing and measuring overbank flow on floodplains suggests that the amount of peak discharge and peak stage reduction possible would be appreciable. Floodplain storage on large rivers is a very important determinant of flood stage and peak discharge. We need to know more about the details of direction, velocity, depth, and variability of overbank flow if we are to allow some of it over the floodplain.

There are other considerations that have had but little study. Overbank flow can scour the surface of a floodplain or deposit sediment on the surface. Both occur and the location and amount are not easily forecast. In fact there are but few studies of the distribution, amount, and texture of sediment laid down by flood water over floodplains. One of the few is that of Wolman and Leopold (1957) who showed that overbank deposition in great floods is relatively small on the average. Summarizing studies of deposition by large floods the valleys of the Ohio, Connecticut, and Kansas River basins, they showed that the average deposition was less than an inch, though in some places it was a few feet. The data for the 1937 flood of the Ohio River, for example, showed that the amount of soil removed was about one quarter the amount that was deposited. But the amount of data on this important matter is pitifully small.

There is a similar dearth of data on the size distribution or texture of sediment deposited overbank during flood as shown in the 1957 report. The 10 examples from different rivers presented show that deposits tend to lie in the fine sand to silt range. Deposits of silt high in organic matter can enhance fertility, but deposits of pure sand would generally be detrimental to agriculture.

The same authors summarized actual current-meter measurements of depth and velocity of flow over floodplains. The data cited totalled only 56 measurements made on 10 river locations. Surely with current-meter measurements during the period of record made at more than 20,000 locations over a period of nearly 100 years, a much larger suite of data could be amassed if a concerted effort were made to canvass the totality of recorded information.

There are obvious constraints to the use of floodplain area for peak flow reduction. One limitation is that many agriculturists may not be willing to accept an easement and would rather take the risk of future flooding rather than to permit their land to be flooded, even if it were seldom and reimbursed.

The degree of possible peak reduction must be ascertained by computation using real, ground-based data. Some reaches of river are hemmed in by commercial or urban development and that makes levees imperative in those areas. But in these leveed reaches, even a modest decrease in flood level may be very effective because a small decrease in peak stage may save much damage.

In summary, theory and practice of proven worth are available to compute the efficacy of using temporary storage of flood water to decrease downstream peaks. This theory has not been put to use in flood control policy. The technology for making the field measurements is available. The purchase of easements for temporary flooding of some areas would decrease the amount of future disaster relief and would be a more permanent solution to some flood control needs.

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